# *Helicon wave produced plasmas for electric propulsion*

Jim Gilland

Ohio Aerospace Institute/

NASA Glenn Research Center/

University of Wisconsin-Madison

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# *Outline*

- Review of Helicon Wave Sources
  - Dispersion
  - Thruster concepts
- Recent Phaedrus helicon experimental results
  - Experimental goals
  - Experimental apparatus
  - Dual Antenna results

# *Helicon wave dispersion and plasma density*

- Approximate helicon dispersion relation for |m|     1:

$$\frac{B}{n_e\ a} \approx \frac{m_0 e}{3.83}\left(\frac{w}{k_z}\right)$$

B = Applied Field, $n_e$ = density, a = plasma radius, 3.83 = zero of Bessel function $J_0$

  - Dispersion indicates the capability for wave propagation at high $n_e$
  - Sources with $n_e$ up to $10^{20}$ $m^{-3}$, $T_e$ ~ 3 eV have been created at rf power ~ 1 kW, a ~ 2 cm (P. Zhu and R. Boswell, Phys. Rev. Lett. 63 (26) 1989)

- High density requires (pick one or more):
  - High $B_0$ - Raises lower hybrid frequency
  - Small radius - plasma confinement issues
  - Low ω - Approach lower hybrid frequency
  - High  k - does not match peak ionization cross section for plasma creation

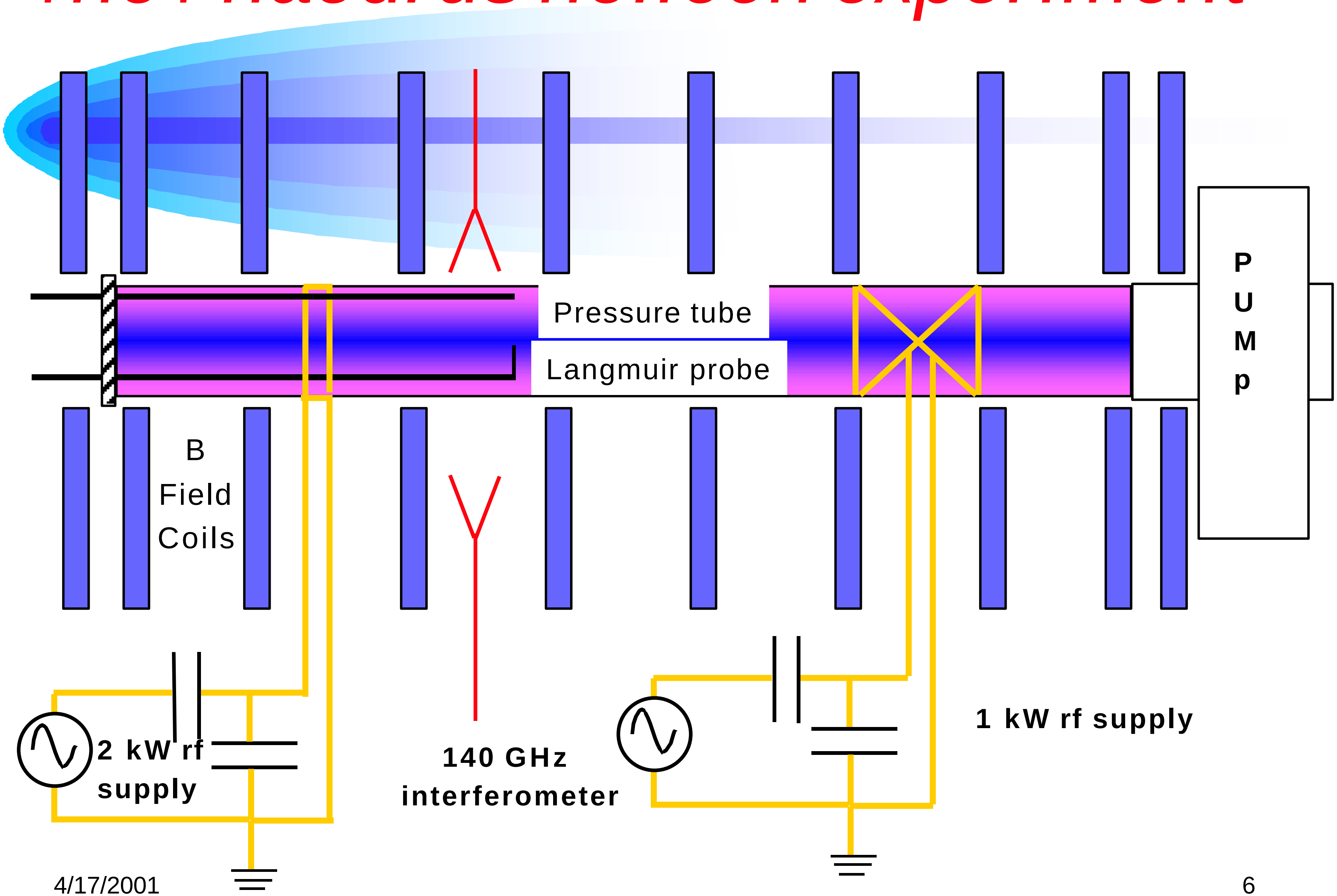
# *Helicon wave thruster concepts*

- Compact ion or plasma source
  - **1cm radius to replace hollow cathode**
  - **Small radius -> high density**
    - $10^{20}$ $m^{-3}$ achieved at 1 kG, kW of power in <u>long</u> tube, radius 1 cm
    - Short tube for thruster applications is a departure from long laboratory sources
- ECR thruster
  - **Generate helicon wave in chamber**
    - $T_{\perp} = T_{||} \sim 3$ eV, high ionization
    - Isotropic $T_e$ reduces plasma losses due to Bohm diffusion (D~ $T_{(\wedge?)}$/B)
  - **Expand magnetic field outside of chamber to ECR region**
    - Continued magnetic expansion past ECR region to accelerate exhaust

# *Experiment to increase helicon density*

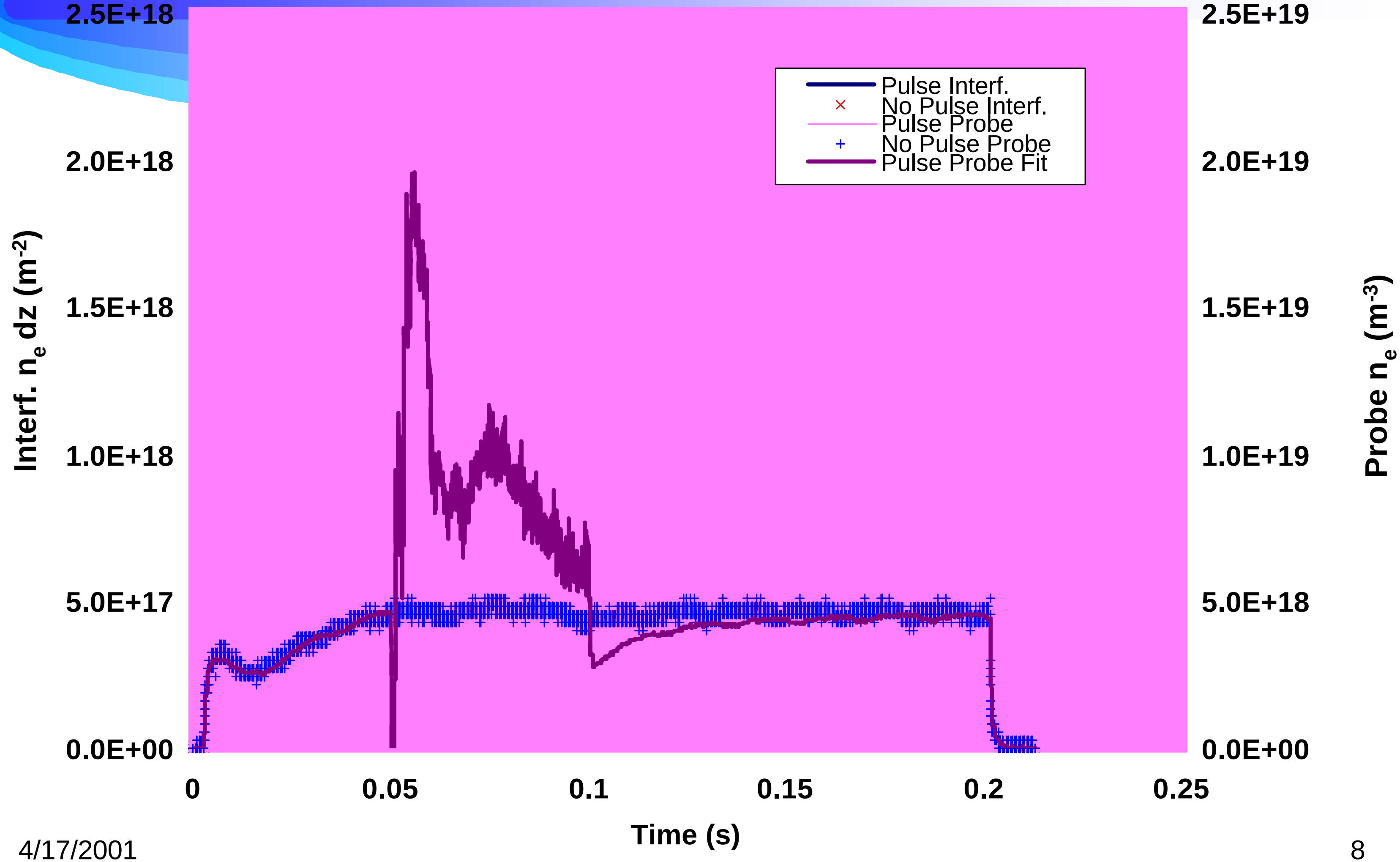
- Use two antennae with different wavelength spectra
  - First longer antenna (steady state) starts plasma
  - Second shorter antenna (pulsed) couples with higher density portion of dispersion
- Use higher power (pulsed) to overcome particle balance issues
  - Neutral pumping still an issue

# The Phaedrus helicon experiment

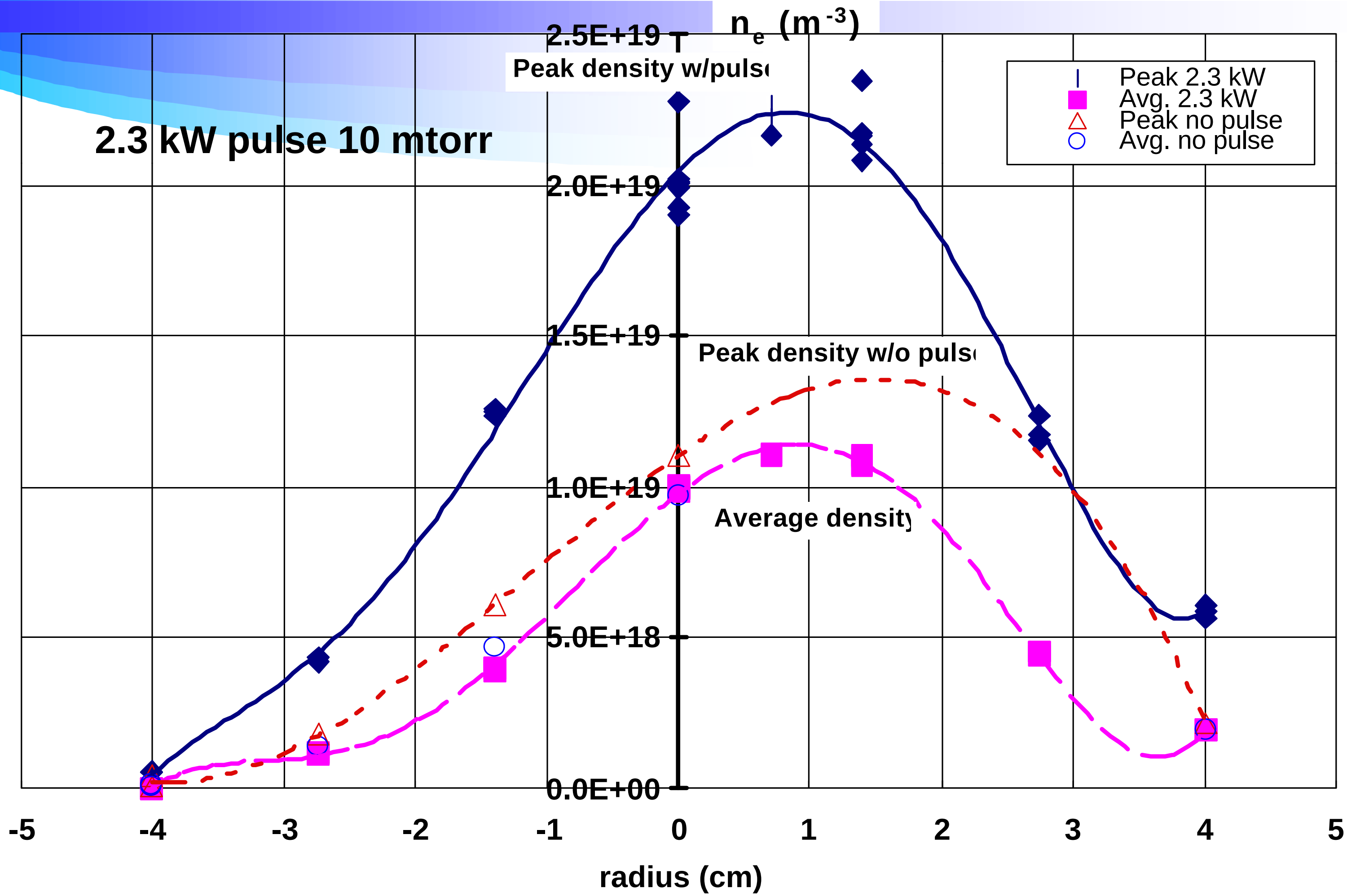


# *Initial Pulsed Results*

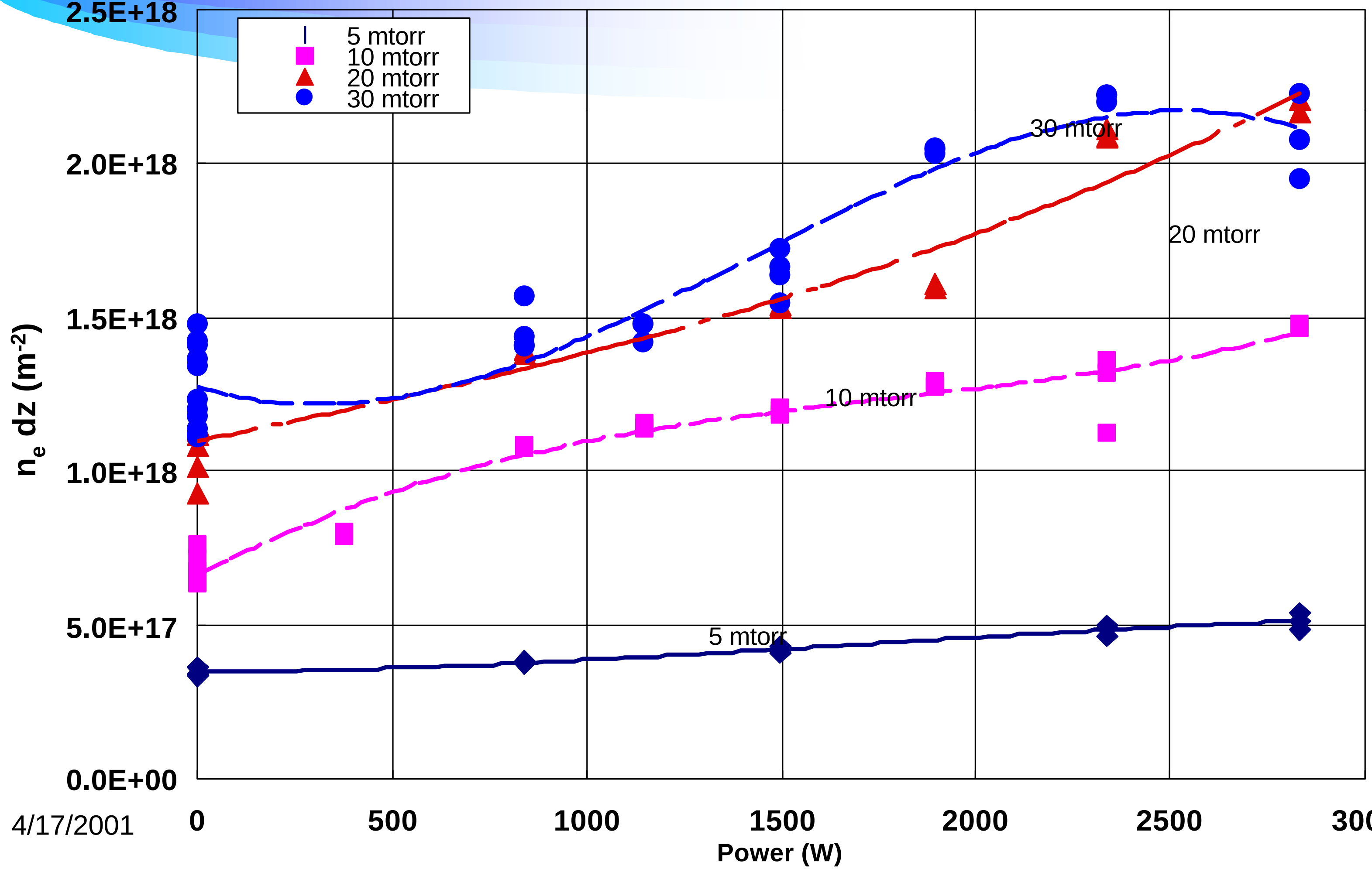
# *Second antenna pulse increases density*



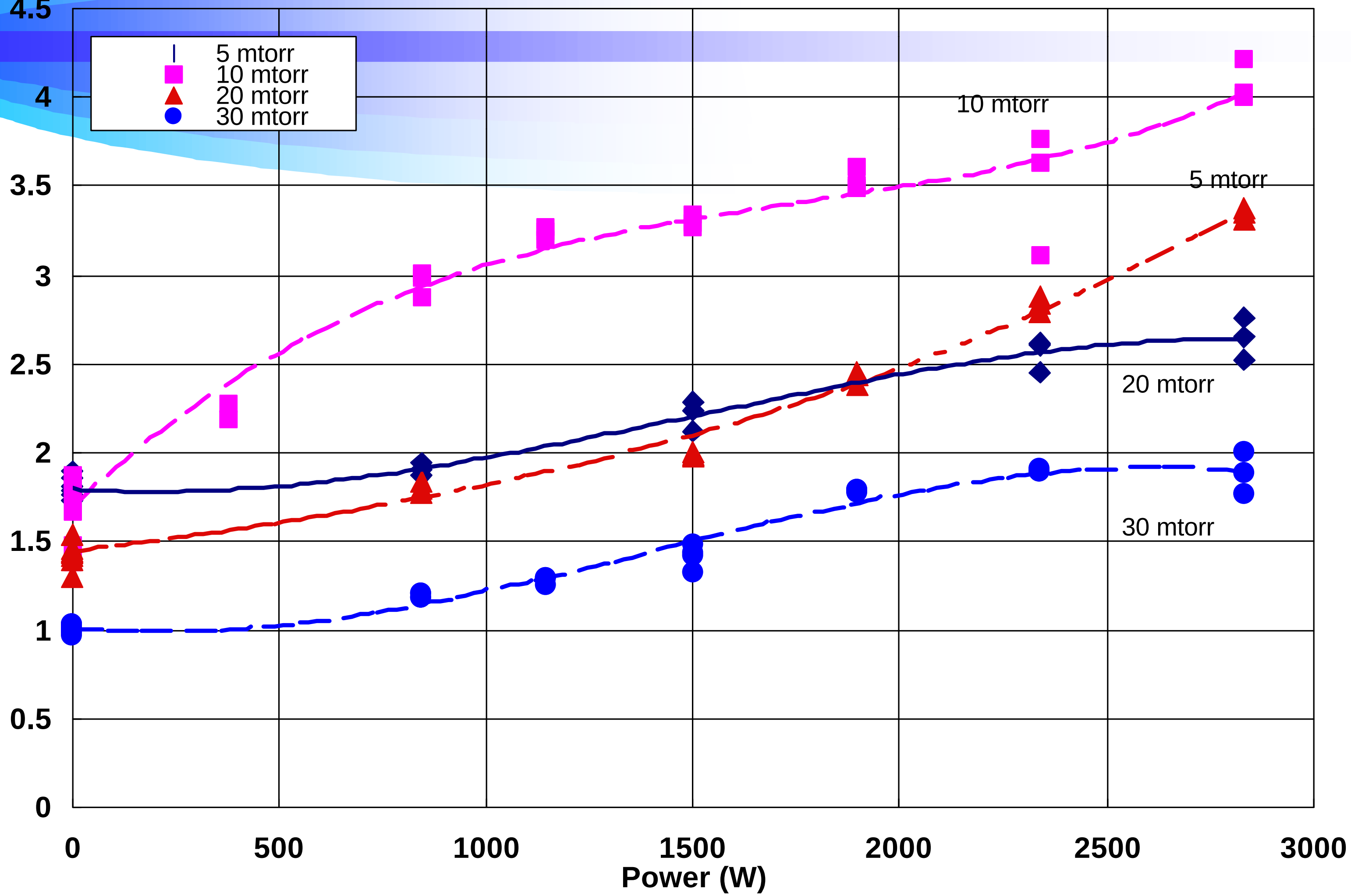
# *Pulsed high power results in broader, denser plasma*



# *Peak density reaches asymptote in pressure, power*



# *Pressure affects steady state density most*



# *Summary*

- Second antenna can provide ~ factor of 2 increase in helicon density
- Particle balance (neutral pumping) appears to limit duration of density increase
- Impacts on thruster designs:
  - Sufficient propellant flow to maintain ionization
  - Conflict between plasma start up (long antenna) and high density operation (short antenna)